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INTRODUCING STAINLESS STEEL LIGHT POLES

Ludwig Anselmini faced the task of capturing part of the light pole market for stainless steel. Before he succeeded he and his associates in this task had to learn about light pole manufacturing and light pole loads, and had to overcome the natural resistance of producers against different design concepts.

Written from interviews with Mr. Ludwig Anselmini of The International Nickel Company, Inc., and published with support of the National Science Foundation. The assistance and cooperation of International Nickel is gratefully acknowledged.

INTRODUCING STAINLESS STEEL LIGHT POLES

In the spring of 1963 I faced the job of capturing part of the light pole market for stainless steel. I had joined The International Nickel Company, Inc., in 1957 as a metallurgical engineer. My previous experience included structural material work in aircraft and fabrication of process equipment. I had been transformed from a metallurgist to a marketing engineer and had been presented with the challenge of developing new uses for nickel-containing materials in the major markets.

In talking with suppliers of light poles in the New York area I found that such poles, generated by the federal road construction program, were made of wood, concrete, steel or aluminum. The greatest use of wood poles was for rural and suburban areas where a pole serves primarily for electric power and telephone lines, and secondarily for supporting a metal bracket arm for a light fixture. In addition, wood poles were used on a few parkways for their esthetic effect and some attention had been given to developing a laminated wood pole. Concrete poles, reinforced with steel bars, did not comprise a growing market because they spall during freezing and thawing weather and are deadly when impacted severely by a vehicle. Our job at Inco was to concentrate on metal light poles and to show the advantages of stainless steel over carbon and low-alloy steel and over aluminum. This was no easy assignment because steel and aluminum were well entrenched. We soon learned that to succeed it would be necessary to develop new and different designs and fabricating procedures for practical production of marketable stainless-steel light poles.

We were spurred by the belief that if this development were successful, it should bring stainless nearer to the long-range goal of also penetrating the markets for flag poles, overhead sign supports and high-voltage transmission poles. Before the job was completed a dozen people from our marketing organization, including district engineers, consultants, and a number of manufacturers had been involved in this effort.

MARKET SURVEY

Our study and evaluation of the metal light-pole market disclosed evidence for a 10-year growth from 120,000 poles per year in 1960 to 170,000 per year in 1970, and a strong and growing position for maintenance-free poles. The capture of 30 percent of the metal-pole market by aluminum, since World War II, indicated a good climate and technical position for maintenance-free stainless steel. However, the commercial position of stainless steel for this application had to be investigated.

In 1963 only carbon or low-alloy steel and aluminum were used for metal light poles. Exhibit 1, Columns 1 and 2, gives the mechanical properties of interest on steel and aluminum for fabricating light poles. I made a brief study mostly by phone calls of how these materials were fabricated into light poles to gain background and because some of the techniques might work for stainless steel.

We learned that steel obtained and retained its leading position by virtue of its low cost

and relatively high strength and modulus of elasticity. Its main disadvantage is that it requires frequent painting. Of course, this can be and is minimized somewhat by hot-dip galvanizing and by use of high-strength low-alloy steels that give improved resistance to rusting. Most tapered steel poles are formed from sheet on a press-brake and longitudinally seam welded (one seam). In davit-type poles the goose neck is formed by bending after welding. Separate mast arms can be bolted or welded to the straight shaft.

Aluminum achieved one-third of the metal light-pole market since 1945 by promotion of its low-maintenance and lightweight features. Redesigning or specification changes surmounted its disadvantages of low modulus of elasticity, poor impact properties, low strength and poor weldability. Some aluminum light poles are press-brake formed from sheet and welded in a manner similar to that used for steel, but most start as a tubular extrusion that is spun-tapered to size. Most aluminum poles with cast bases meet the Federal break-away safety requirements.*

DEVELOPMENT OF A COMPETITIVE STAINLESS-STEEL LIGHT POLE

Column 3 of Exhibit 1 gives the mechanical properties of the chromium-nickel stainless steel used for light poles. A comparison of these properties with those for steel and aluminum, also given in Exhibit 1, shows that the stainless steel offers more strength and better ductility than the others. In addition, its stiffness (modulus of elasticity) is identical to that of the steels.

Corrosion resistance is the main advantage of stainless steel. For more than 30 years nickel-containing stainless steel has demonstrated its resistance to corrosion in urban and industrial environments. It has been accepted widely for building and store front entrances and building sheathings, in the same atmospheres which light poles must endure.[3]

Although dirt accumulation is inevitable for all materials in polluted atmospheres, nickel stainless steel tends to retain its metallic luster through the natural washing action of the rain. Also, it offers resistance to the salts used in winter snow removal . . . salts which can be highly corrosive to the metals, alloys and coatings ordinarily used for light poles.

It was not enough for stainless steel to have highly favorable mechanical and corrosion-resistance properties. It had to be economical in spite of the higher cost per pound. We tried to achieve this by superior design. We learned that the design technology for poles was highly empirical and design efficiency needed refinement if the most desirable economic position was to be for stainless steel.

To begin with we wanted to know the forces to which light poles are subject. The weight of pole and light fixture is one such force; wind produces another. To learn more about the wind forces Inco arranged for tests by the Warnock Hersey Company in Toronto who exposed light poles to the blast of an airplane propeller which generated a wind up to 100 miles per hour. The light poles were equipped with strain gauges to

*Federally sponsored highways require that poles have break-away safety bases unless they are placed more than 30 feet from the edge of the road.

measure bending stresses and the natural frequencies and modes of vibration were also investigated.

Inco also engaged the services of a specialist in light gauge design. Mr. W. R. Petri had been an aircraft designer with Messerschmidt. He now practiced as a consultant in Toronto. Based on the wind tunnel results he was able to apply basic equations, which he had developed for tapered cantilever beams,[4] to evolve an efficient and effective method of light-pole design analysis. A sample of his calculations for tapered light poles is presented in Appendix A.

Using Petri's approach, we analyzed representative light-pole configurations. The results indicated that with wall thicknesses in the range .062 to .072 inch, light-weight designs were possible within the pricing structure set by the competing aluminum light-pole market.

I now went travelling. I visited the major producers of light poles to discuss these designs and their economic aspects and to try to interest them in producing stainless-steel light poles. At first no one wanted to "break the ice" and progress was slow.

Finally several light-pole producers decided to fabricate a few experimental stainless-steel units based on their own design criteria. These poles were commercially unfavorable because they used heavy wall thickness and the material costs were too high. This happened despite all our work and discussions on proper design.

Discouraged but not dismayed, we persisted in emphasizing the proper design for stainless poles with the light-pole producers. Eventually we were successful when the Millerbernd Manufacturing Company, Winsted, Minnesota, took advantage of our lightweight designs and produced several experimental poles. This production established favorable fabricating and material costs and indicated that orders could be filled using ¼ hard, AISI Type 301 (17 chromium-7 nickel) stainless steel (Exhibit 1). (Fabricating details are discussed in Appendix B).

To stimulate production of stainless-steel light poles at Millerbernd, we ordered 10 poles for installation at our new Paul D. Merica Research Laboratory and 12 poles to be used for trial or demonstration installations throughout the country. The first trail installation was in Philadelphia, Exhibit 2. Trial installations followed soon in St. Paul and Toronto. We arranged to give the attendant publicity a wide distribution.

Our publicity department assigned a man to this job. He liked the topic and spent about a quarter of his time during the next year arranging for radio commercials, articles in trade magazines for municipal officials, illuminating engineering magazines, our own publications and so on.

In conjunction with efforts by our district offices* and the publicity campaign, orders were developed for production quantities of stainless-steel light poles. Before the end of 1965, 24 poles had been installed and the Millerbernd Manufacturing Company had orders for 148 more, including repeat orders from Philadelphia and St. Paul. By

*International Nickel has 11 district offices in the USA (and similar activities in other countries) primarily to develop new markets for nickel and its alloys.

mid-1968 Millerbernd had sold more than 4000 stainless poles in competition with aluminum. Many of the other light-pole manufacturers were encouraged in 1965 by International Nickel to investigate stainless light-pole production and marketing in conjunction with stainless-steel producers such as U. S. Steel Corporation, Crucible Steel Company, Republic Steel Corporation and Allegheny Ludlum Steel Corporation. Typical examples of stainless-steel light poles are shown in Figures 2 to 4 of Exhibit 2.

Before the end of 1968, W. R. Keegan & Company (formerly Sectional Poles, Inc.), Havertown, Pa., had sold about 1000 poles that feature construction with telescoping 6-foot sections that are fitted together at the job site, as shown by Figure 5 of Exhibit 2. Union Metal Manufacturing Company, Canton, Ohio, has stainless-steel light poles as catalog items. By 1970, about 10,000 stainless steel light poles had been installed and new installations continue at the rate of about 4000 per year.

METAL LIGHT-POLE DIMENSIONS AND WEIGHTS

We have mentioned that designers, sponsored by International Nickel, analyzed the load requirements established by the light-pole industry and selected stainless wall thicknesses of .062 to .072 inch. This gives a material weight of 160 pounds for a typical stainless pole.

A very popular-sized light pole comprises a 25-foot shaft with a 9-foot bracket arm. It will support a luminaire 28 feet above the ground, as specified by NEMA, with a transformer base, and 26 feet in the air without the transformer base. In carbon or low-alloy steel this pole is supplied with an 11-gage (0.122 inch) wall, and weighs 335 pounds. In aluminum it has a 0.188-inch wall thickness and weighs 160 pounds. The aluminum and stainless-steel poles cost about 1.8 times as much as a carbon or low-alloy steel pole.

The aluminum industry has proved for us that purchasers of metal light poles are willing to pay a 50 to 100 percent premium for a pole that needs no maintenance. By taking advantage of this preference, stainless steel is fitting into this market and solving some of the problems that are arising because of replacements of incandescent types with heavier lighting units comprising mercury-vapor luminaires.

The new lights have a ballast integral with the bulb and replace a 35-pound incandescent unit with an 80-pound unit with a larger projected area for more wind loading at the end of the bracket arm. Here is an opportunity to use the superior strength of stainless steel to advantage and this is being done in many cities.[5]

The light pole market is expanding under the pressure of better lighting requirements for traffic safety on all streets and highways and for citizen protection at night in urban areas. The sales appeal of brightly lighted parking lots at shopping centers and theaters and well-illuminated gasoline stations has led to the use of more light poles and larger luminaires.

The federal highway program advocates illumination of interchanges and urban by-passes as a minimum requirement. As already mentioned, federally sponsored highways require that poles have

break-away safety bases unless they are placed more than 30 feet from the road's edge. Stainless designs that meet all break-away requirements have been tested and are being used. Incidentally, the break-away base types are used only on highways where there is no pedestrian traffic. The growth of this program plus the movement toward more suburban shopping areas, and the "downtown" area improvements to counteract this trend, are predicted to increase the light-pole market by around 3 to 5 percent each year for the next ten years (1969-1979).

Development of the stainless-steel light pole market and the attendant build-up of manufacturing potential and capability will help greatly in penetrating the flag-pole, overhead sign-support and high voltage transmission-pole markets with stainless steel. These associated components can be built from sheets, basically the same way as light poles, and the low-cost fabricating techniques, learned and used for light poles, will apply.

Nominal Mechanical Properties of Metals Used to Fabricate Light Poles

METAL	Steel, Hot-Rolled Carbon [a] or High-Strength Low-Alloy [b]	Aluminum, [c] 6063 Alloy T6 Temper	Stainless Steel, AISI Type 301 1/4 Hard [d]
TENSILE PROPERTIES			
Tensile Strength, psi	70,000	35,000	125,000 [d]
Yield Str (0.2% Offset), psi	45,000	31,000	75,000 [d]
Elongation (2 in.), %	22	12	25
STIFFNESS DATA			
Modulus of Elasticity, psi	29,000,000	10,000,000	29,000,000
Modulus of Rigidity, psi	12,000,000	3,800,000	12,000,000

[a] Reference 1 (0.2% C, 0.6% Mn steel).

[b] ASTM Standards, Part 3, Designation A 374, "High-Strength Low-Alloy Cold-Rolled Steel Sheets and Strip.

[c] Reference 2.

[d] Nickel stainless steels are improved in strength and hardness through cold working. The normal processes used in stainless light-pole manufacturing increase the strength over these values of the 1/4 hard starting material.

EXHIBIT 1

Figure 1. Philadelphia was the first city to install nickel stainless steel light poles for modernization of downtown areas. Other cities, industrial parks and suburban developments, across the country, have incorporated these light poles in their planning.

Figure 2. This 12-foot pole illuminates a city park in Montreal, Quebec. It was fabricated from Type 301 stainless steel with a No. 2B finish.

EXHIBIT 2

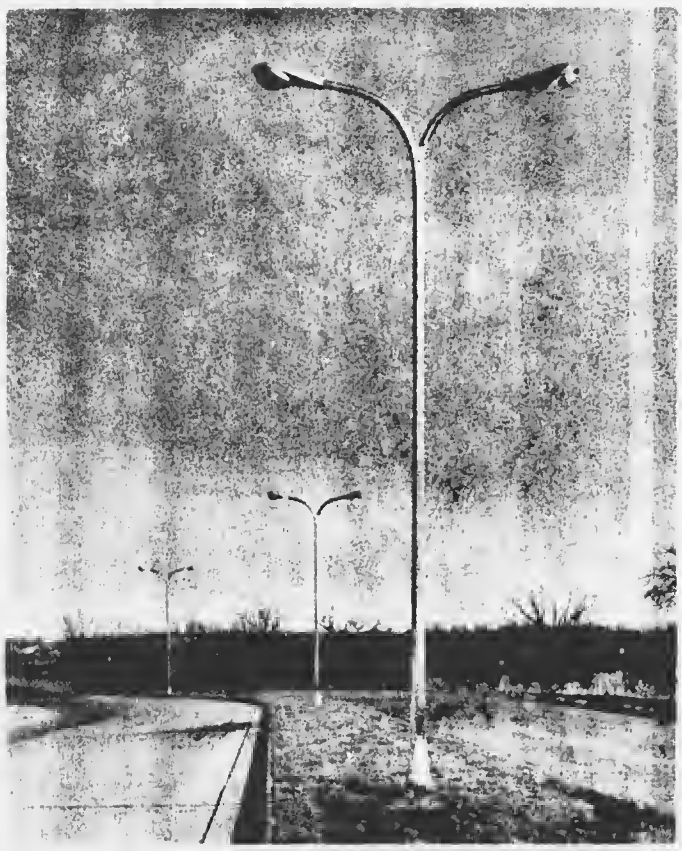


Figure 3. St. Paul, Minnesota, specified 35-foot octagonal, twin-mastarm, stainless-steel poles for boulevard use.

Figure 4. More than 50 custom-designed, star-shaped, 14-foot stainless steel light poles are in use to illuminate the plaza and walkways at the new Civic Center, Rochester, N. Y.

EXHIBIT 2

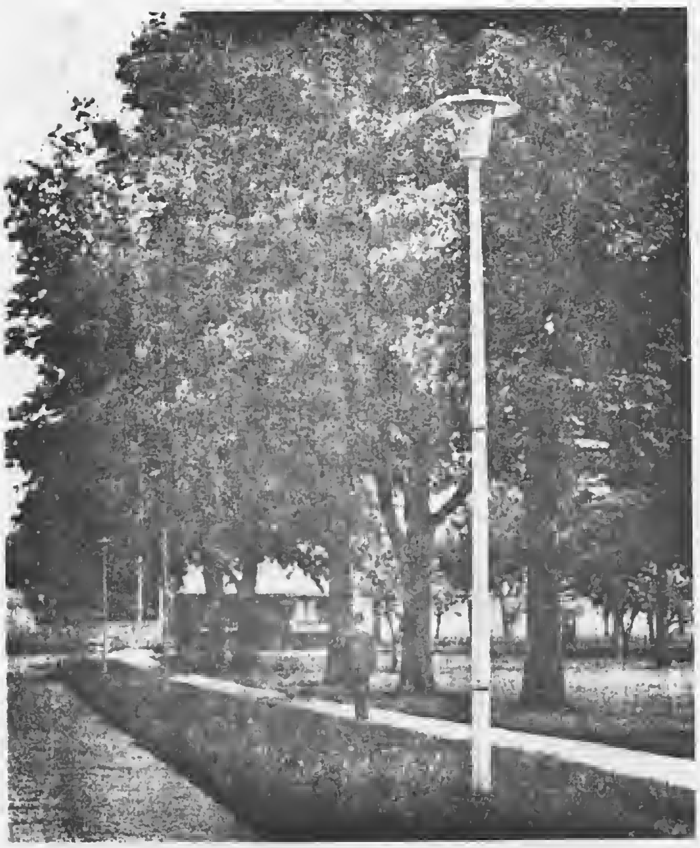
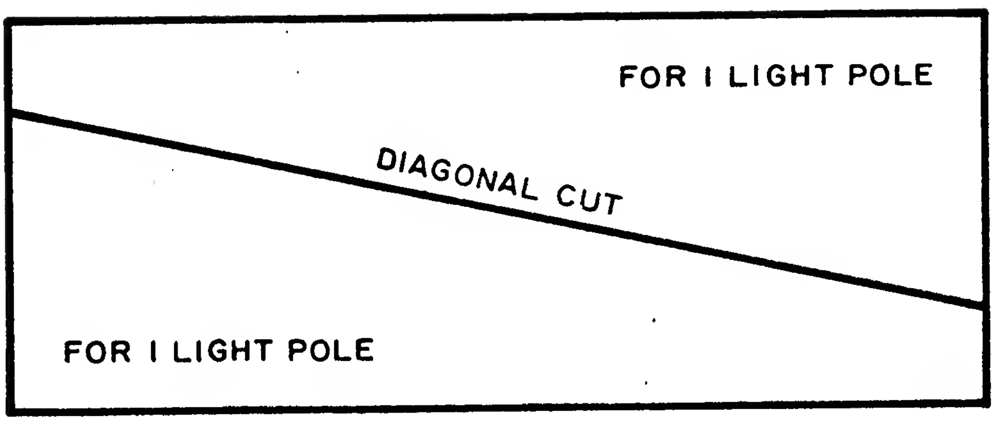


Figure 5. This sectional stainless-steel light pole can be field-assembled easily by fitting one 6-foot light-weight tapered section over another. Such poles can be packaged for delivery and storage as a complete lighting unit in a 7-foot carton.

EXHIBIT 2



Rectangular sheet of metal is cut as shown for two tapered light poles. Each cut piece is formed on a press brake into a round, hexagon or octagon (etc.) and welded (1 seam).

Figure 6 · Schematic illustration of the cutting of a rectangular sheet of metal for fabrication of two tapered stainless-steel light poles.

EXHIBIT 2

APPENDIX A

Sample Calculations of Stresses and Deflections for a Stainless Steel Lighting Standard (Pole)* ECL 165

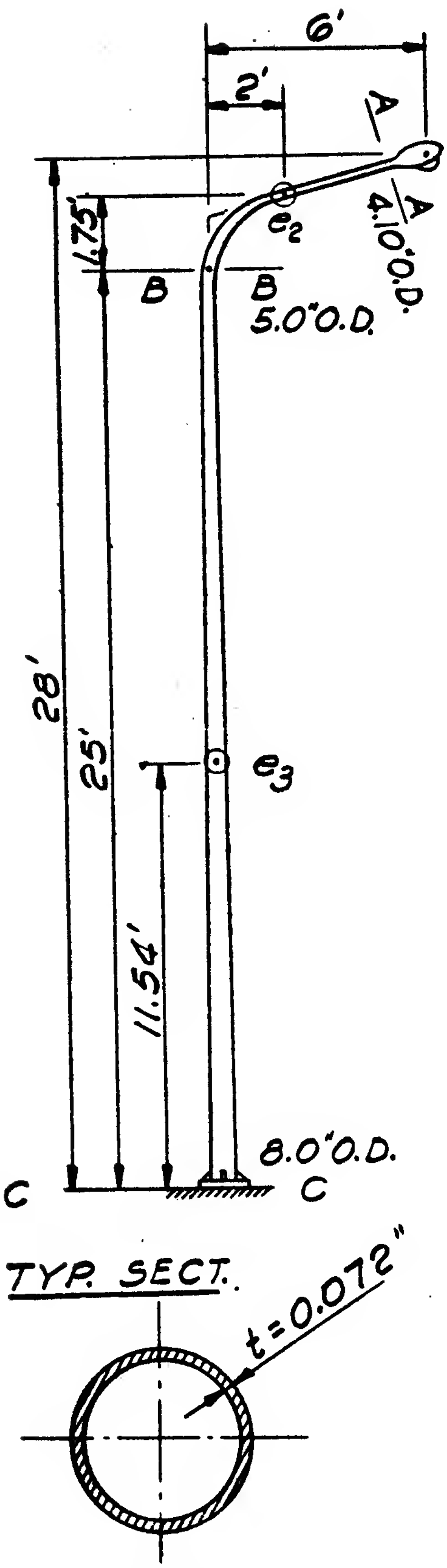


FIG. 1A

A. LOADING.

100 MPH Wind

Wind pressure on projected area of round surface = 20.5 Lbs/Ft.^{2}

Wind pressure on all other surfaces = 35.8 Lbs/Ft.^{2}

B. LUMINAIRE.

Mercury vapor, weight $G_1 = 50$ Lbs

Projected area $A_1 = 25$ Ft.^{2}

Wind load on Luminaire

$F_1 = 2.5 \times 35.8 = 89.5$ Lbs.

C. DAVIT.

Projected area $A_2 = \left(\frac{4.1+5.0}{2\times12}\right)\times 6 = 2.28$ Ft.^{2}

Wind load on Davit $F_2 = 2.28 \times 20.5 = 46.8$ Lbs.

C.G. of projected area

$$e_2 = \frac{6}{3}\left(\frac{2\times5+4.1}{5+4.1}\right) = 3.10 \text{ Ft.}$$

D. SHAFT.

Projected area $A_3 = \left(\frac{5+8}{2\times12}\right)\times 25 = 13.55$ Ft^2

Wind load on Shaft $F_3 = 13.55 \times 20.5 = 278.5$ Lbs.

C.G. of projected area $e_3 = \frac{25}{3}\left(\frac{2\times8+5}{8+5}\right) = 13.46$ Ft.

11.54 "

25.00 Ft.

E. MATERIAL.

Stainless steel 301; ¼ hard

Yield Strength $\sigma_{0.2} = 75{,}000$ psi min.

$E = 29\times10^6$ psi

Wall thickness $t = 0.072$"

F. STRESSES.

Wind ⊥ to the plane of Davit

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* These suggested calculations, made in August, 1963, by W. R. Petri, Consultant and Professional Engineer, Galt, Canada, for International Nickel are for information only. International Nickel does not assume responsibilty for users designs.

1. SECTION B-B

a. Bending Moment due to wind.

$M_4 = 89.5 \times (28-25) + 46.8 \times 1.75 = 268.5 + 81.9$
$= 350.4$ Ft. Lbs. $=$ 4205 in. Lbs.

Bending due to weight of Luminaire

$M_5 = 50.6 = 300$ Ft. Lbs. $=$ 3600 in. Lbs.

b. Propeties of Cross Section B-B:

Tube 5×0.072
Area $= 1.115$ in.^{2}
Moment of Inertia $I = 3.385$ in.^{4}
Section Modulus $S = 1.354$ in.^{3}

c. Stresses.

Bending stress due to wind

$$\sigma_4 = \frac{4205}{1.354} = \pm 3105 \text{ psi}$$

Max. shear stress due to wind

$$\tau_{4max.} = \frac{4}{3} \times \frac{89.5 + 46.8}{1.115} = 165 \text{ psi}$$

Bending stress due to weight of Luminaire:

$$\sigma_5 = \frac{3600}{1.354} = \pm 2660 \text{ psi}$$

Compressive stress due to weight of Luminaire:

$$\sigma_6 = \frac{50}{1.115} = 45 \text{ psi}$$

The resultant stress in bending:

$$\sigma_{4.5} = \frac{3105 + 2660}{\sqrt{2}} = 4075 \text{ psi}$$

and the compression $\sigma_6 = 45$

$\sigma_{4.5.6} = 4120$ psi

Torsional Moment

$M_T = 89.5 \times 6 + 46.8 \times 2 = 666.6$ Ft. Lbs.
$= 8000$ in. Lbs.

Shear stress due to torsion:

$$\tau_7 = \frac{8000}{2 \times 1.354} = 2950 \text{ psi}$$

Max. shear stress $\tau_{4.7} = 165 + 2950$
$= 3115$ psi

The resultant stress is the combination of σ_4, τ_7 and σ_6

$$\sigma_{res} = \sqrt{3105^2 + 3\times 2950^2} + 45$$
$$= \sqrt{9.64\times10^6 + 26.11\times10^6} + 45$$
$$= 5979 + 45 = \underline{6024\ psi}$$

2. Section C-C

a. Properties at Section C-C: Tube 8×0.072

Area = 1.795 In.^{2}

Moment of Inertia I = 13.78 in.^{4}

Section Modulus S = 3.445 in.^{3}

b. Bending Moment due to wind

$$M_B = 89.5\times 28 + 46.8\times 26.75 + 278.5\times 11.54$$
$$= 2505 + 1252 + 3215 = 6972\ \text{Ft. Lbs.} = \underline{83{,}650\ \text{in. Lbs}}$$

Bending Moment due to weight of Luminaire and torsional moment are the same as for Section B-B.

The weight of the Davit and the shaft with $a_o = 6.28$

$$G_2 = \frac{6.28}{2}\, 0.29\times(25+6)\times12\times0.072\,(4+2.05) = \underline{145.6\ \text{Lbs.}}$$

c. Stresses.

Bending stress due to wind $\sigma_8 = \dfrac{83{,}650}{3.445} = \pm\ \underline{24{,}300\ psi}$

Max. shear stress due to wind $\tau_{8max} = \dfrac{4}{3}\times\dfrac{89.5+46.8+278.5}{1.795} = \underline{308\ psi}$

Bending stress due to weight of Luminaire

$$\sigma_9 = \frac{3600}{3.445} = \pm\ \underline{1045\ psi}$$

Compressive stress due to weight of Luminaire + Davit + Shaft

$$\sigma_{10} = \frac{50 + 145.6}{1.795} = -\ \underline{109\ psi}$$

Shear stress due to torsion

$$\tau_{11} = \frac{8000}{2\times3.445} = \underline{1160\ psi}$$

The resultant stress

$$\sigma_{res} = \sqrt{24{,}300 + 3 \times 1160^2} + 109 = \sqrt{590.49 \times 10^6 + 3.04 \times 10^6} + 109$$
$$= 24{,}360 + 109 = \underline{24{,}469 \text{ psi}}$$

Now $\dfrac{E}{\sigma_{0.2}} \times \dfrac{t}{D} = \dfrac{29 \times 10^6}{75 \times 10^3} \times \dfrac{72 \times 10^{-3}}{(8 - 0.072)} = 3.51$

For above value $\dfrac{\sigma_{ULT}}{\sigma_{0.2}} = 0.865$ (see Fig. 8 of Commentary on "Light Gage Cold-Formed Steel Design Manual", AISI). With safety factor $= 1.95$ allowabe commpressive stress is :

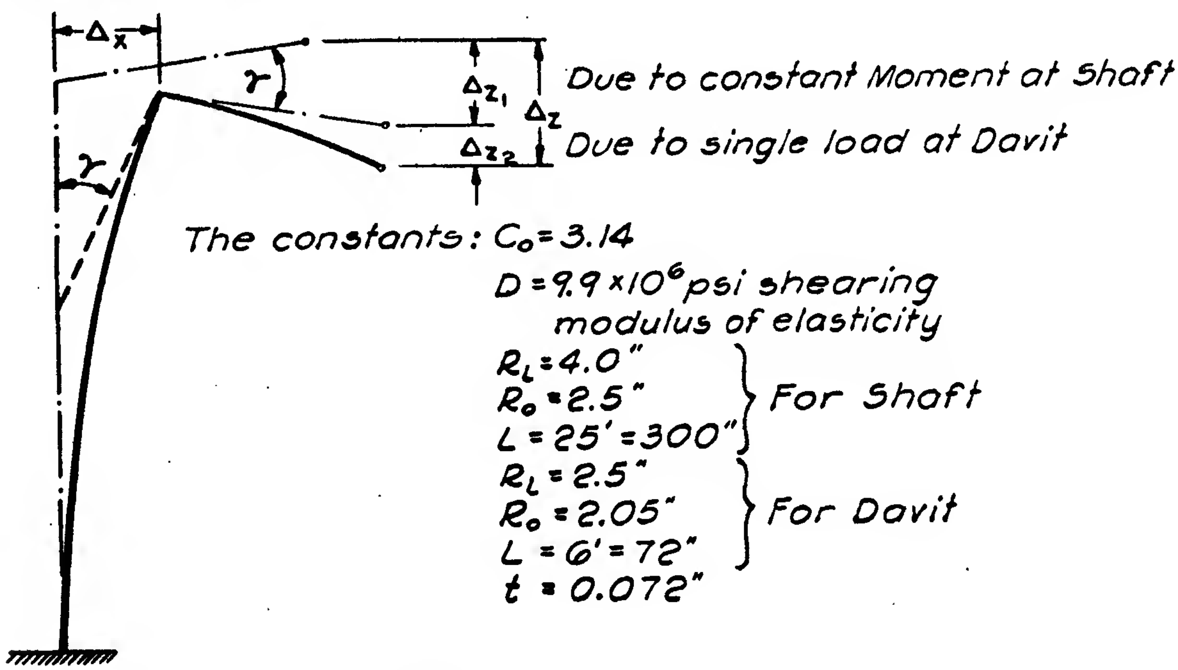
$$\sigma_{ALL\,COMP} = \frac{0.865 \times 75008}{1.95} = \underline{33{,}250 \text{ psi} > 24{,}469 \text{ psi}}$$

3. **Anchor Bolts** - Four Anchor Bolts placed on 13" center diameter.

The max. tensile force for one Anchor Bolt is :

$$F_B = \frac{83{,}650 + 3600}{2 \times \frac{13}{\sqrt{2}}} = 4740 \text{ Lbs.}$$

9. **Deflections**



The constants: $C_o = 3.14$

$D = 9.9 \times 10^6$ psi shearing modulus of elasticity

$\left.\begin{array}{l} R_L = 4.0" \\ R_o = 2.5" \\ L = 25' = 300" \end{array}\right\}$ For Shaft

$\left.\begin{array}{l} R_L = 2.5" \\ R_o = 2.05" \\ L = 6' = 72" \end{array}\right\}$ For Davit

$t = 0.072"$

FIG. 2A

$$\Delta_x = \frac{M_B}{2 \times E \times C_o \times t \times R_o^2}\left(\frac{L}{R_L}\right)^2; \quad M_B = 3600 \text{ in. Lbs. (see Paragraph F. 1. a.)}$$

$$\Delta_x = \frac{3600}{2 \times 29 \times 10^6 \times 3.14 \times 0.072 \times 2.5^2}\left(\frac{300}{4}\right)^2 = \frac{3.6 \times 10^3 \times 5.56 \times 10^3}{2 \times 29 \times 10^6 \times 3.14 \times 7.2 \times 10^{-2} \times 2.5^2}$$

$\underline{\Delta_x = 0.247"}$

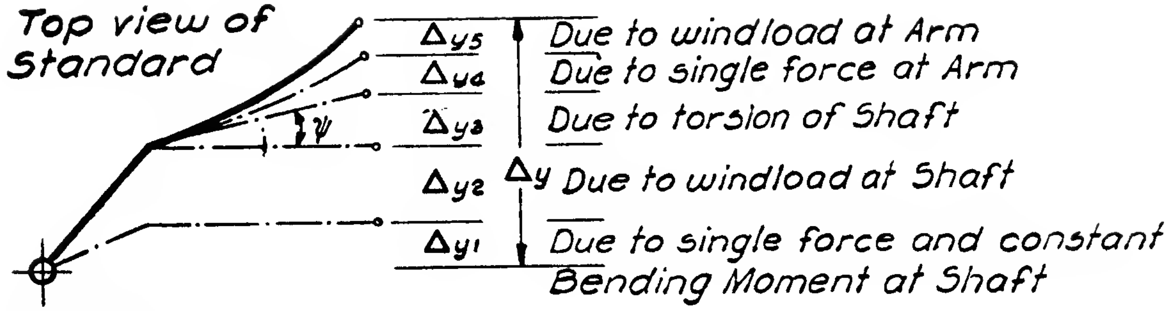


FIG. 3A

$$\gamma = \frac{M_B \times L \times (R_L + R_o)}{2 \times E \times C_o \times t \times R_L^2 \times R_o^2} \; ; \; M_B = 3600 \text{ in. Lbs.}$$

(see Paragraph F. 1. a.)

$$\gamma = \frac{3600 \times 300\,(4.0 + 2.5)}{2 \times 29 \times 10^6 \times 3.14 \times 0.072 \times 4^2 \times 2.5^2}$$

$$= \frac{3.6 \times 10^3 \times 3 \times 10^2 \times 6.5}{2 \times 29 \times 10^6 \times 3.14 \times 7.2 \times 10^{-2} \times 16 \times 6.25}$$

$$\gamma = \frac{3.6 \times 3 \times 6.5}{2 \times 29 \times 3.14 \times 7.2 \times 16 \times 6.25} = \underline{0.536 \times 10^{-3}} \text{ (in Radians)}$$

$$\Delta_{z_1} = L \times \gamma = 72 \times 0.536 \times 10^{-3} = 38.6 \times 10^{-3} = \underline{0.0386''}$$

$$\Delta_{z_2} = \frac{2F}{3 \times E \times C_o \times t} \left(\frac{L}{R_L + R_o}\right)^3 \left\{1 + \frac{3}{4}\left(1 + \frac{R_o}{R_L}\right)^2\right\} ; F = 50 \text{ Lbs. (Weight of Luminaire)}$$

$$\Delta_{z_2} = \frac{2 \times 50}{3 \times 29 \times 10^6 \times 3.14 \times 0.072} \left(\frac{72}{2.5 + 2.05}\right)^3 \left\{1 + \frac{3}{4}\left(1 + \frac{2.05}{2.5}\right)^2\right\}$$

$$= \frac{100 \times 4.075 \times 10^3 \times 3.03}{3 \times 29 \times 10^6 \times 3.14 \times 7.2 \times 10^{-2}} = \frac{4.075 \times 3.03}{3 \times 2.9 \times 3.14 \times 7.2} = \underline{0.0626''}$$

$$\underline{\Delta_z} = \Delta_{z_1} + \Delta_{z_2} = 0.0386 + 0.0626 = \underline{0.1012''}$$

$$\Delta_{y_1} = \frac{2F}{3 \times E \times C_o \times t} \left(\frac{L}{R_L + R_o}\right)^3 \left\{1 + \frac{3}{4}\left(1 + \frac{R_o}{R_L}\right)^2\right\} + \frac{M_B}{2 \times E \times C_o \times t \times R_o} \left(\frac{L}{R_L}\right)^2$$

$$F = 89.5 + 46.8 = 136.3 \text{ Lbs. (Davit and Shaft)}$$

$$M_B = M_4 = 4205 \text{ in. Lbs (see Paragraph F. 1. a.)}$$

$$\Delta y_1 = \frac{2\times 136.3}{3\times 29\times 10^6\times 3.14\times 0.072}\left(\frac{300}{4+2.5}\right)^3\left\{1+\frac{3}{4}\left(1+\frac{2.5}{4}\right)^2\right\} + \frac{4205}{2\times 29\times 10^6\times 3.14\times 0.072\times 2.5}\left(\frac{300}{4}\right)^2$$

$$= \frac{2\times 1.363\times 10^2\times 9.83\times 10^4\times 2.98}{3\times 29\times 10^6\times 3.14\times 7.2\times 10^{-2}} + \frac{4.205\times 10^3\times 5.56\times 10^3}{2\times 29\times 10^6\times 3.14\times 7.2\times 10^{-2}\times 2.5}$$

$$\underline{\Delta y_1} = \frac{2\times 1.363\times 9.83\times 2.98}{3\times 2.9\times 3.14\times 0.72} + \frac{4.205\times 5.56}{2\times 2.9\times 3.14\times 0.72\times 2.5}$$

$$= 4.060 + 0.714 = \underline{4.774}''$$

$$\Delta y_2 = \frac{pL^4}{6\times E\times C_o\times t\times R_L^2}\left\{2 - \frac{1+\frac{R_o}{R_L}+2\left(\frac{R_o}{R_L}\right)^2}{\left(1+\frac{R_o}{R_L}\right)^3}\right\} \quad p = \frac{20.5}{144} = 0.1423\ psi$$

$$\frac{R_o}{R_L} = \frac{2.5}{4} = 0.625$$

$$\Delta y_2 = \frac{0.1423\times 300^4}{6\times 29\times 10^6\times 3.14\times 0.072\times 4^2}\left\{2 - \frac{1+0.625+2\times 0.625^2}{(1+0.625)^3}\right\}$$

$$\underline{\Delta y_2} = \frac{0.1423\times 81\times 10^8}{6\times 29\times 10^6\times 3.14\times 7.2\times 10^{-2}\times 16}\left\{2 - \frac{2.406}{4.29}\right\}$$

$$= \frac{1.423\times 8.1\times 10^2}{6\times 2.9\times 3.14\times 7.2\times 1.6} = \underline{1.832}''$$

$$\psi = \frac{M_T\times L(R_L+R_o)}{4\times D\times C_o\times t\times R_L^2\times R_o^2}\ ;\ M_T = 8000\ in.\ Lbs. (see\ Par.\ F.\ I.\ c.)$$

$$\psi = \frac{8000\times 300(4+2.5)}{4\times 9.9\times 10^6\times 3.14\times 0.072\times 4^2\times 2.5^2} = \frac{2.4\times 10^6\times 6.5}{4\times 9.9\times 10^6\times 3.14\times 7.2\times 10^{-2}\times 16\times 6.25} =$$

$$= \frac{2.4\times 6.5}{4\times 0.99\times 3.14\times 7.2\times 1.6\times 6.25} = 0.01743\ (Radians)$$

$$\underline{\Delta y_3} = L\times\psi = 72\times 0.01743 = \underline{1.255}''$$

$$\Delta y_4 = \frac{2F}{3\times E\times C_o\times t}\left(\frac{L}{R_L+R_o}\right)^3\left\{1+\frac{3}{4}\left(1+\frac{R_o}{R_L}\right)^2\right\};\ F = 89.5\ Lbs.\ (see\ Par.\ B.\ Luminaire)$$

$$= \frac{2\times 89.5}{3\times 29\times 10^6\times 3.14\times 0.072}\left(\frac{72}{2.5+2.05}\right)^3\left\{1+\frac{3}{4}\left(1+\frac{2.05}{2.5}\right)^2\right\}$$

$$\underline{\Delta y_4} = \frac{2\times 89.5\times 4.075\times 10^3\times 3.03}{3\times 29\times 10^6\times 3.14\times 7.2\times 10^{-2}} = \frac{2\times 8.95\times 4.075\times 3.03}{3\times 29\times 3.14\times 7.2} = \underline{0.112}''$$

$$\Delta_{y_5} = \frac{p \times L^4}{6 \times E \times C_o \times t \times R_L^2}\left\{2 - \frac{1+\frac{R_o}{R_L}+2\left(\frac{R_o}{R_L}\right)^2}{\left(1+\frac{R_o}{R_L}\right)^3}\right\}; \quad p = 0.1423\ psi \quad \frac{R_o}{R_L} = \frac{2.05}{2.5} = 0.82$$

$$\Delta_{y_5} = \frac{0.1423 \times 72^4}{6 \times 29 \times 10^6 \times 3.14 \times 0.072 \times 2.5^2}\left\{2 - \frac{1+0.82+2 \times 0.82^2}{(1+0.82)^3}\right\}$$

$$= \frac{0.1423 \times 26.9 \times 10^6}{6 \times 29 \times 10^6 \times 3.14 \times 7.2 \times 10^{-2} \times 6.25}\left\{2 - \frac{3.165}{6.03}\right\}$$

$$\underline{\Delta_{y_5}} = \frac{1.423 \times 2.69 \times 1.475}{6 \times 29 \times 3.14 \times 0.72 \times 6.25} = \underline{0.023''}$$

$$\Delta y = \Delta_{y_1} + \Delta_{y_2} + \Delta_{y_3} + \Delta_{y_4} + \Delta_{y_5} = 4.774 + 1.832 + 1.255 + 0.112 + 0.023$$

$$\underline{\Delta y = 7.996'' \approx 8''}$$

APPENDIX B

PROCEDURES DEVELOPED TO PRODUCE AND ERECT STAINLESS POLES

Tapered stainless-steel light poles are fabricated from sheet, as indicated in Figure 6, of Exhibit 2, just like ordinary steel poles (already mentioned). The difference is that after welding, instead of being blast cleaned to white metal and prime painted, they are either belt ground, or blasted with glass beads, or treated in a bath containing HNO_3 and rinsed thoroughly.[6] After drying they are wrapped for shipment.

The sectional stainless-steel pole comprising tapered 6-foot lengths, Figure 5, also is fabricated from sheet. These tapered lengths are nested for shipment.

Lightweight types of stainless-steel poles are erected by setting in the ground to a suitable depth; no corrosion protection is needed. Heavier poles use a stainless-steel base flange and stainless-steel anchor bolts which are immersed to a suitable depth in concrete. The anchor bolts, head down, are supported in a wire cage before the concrete is poured.

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